Performance analysis of IRA codes for underwater acoustic OFDM communication system

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Abstract—**Recently, multicarrier modulation in the form of orthogonal frequency division multiplexing (OFDM) has been actively investigated in underwater acoustic communications for its effective algorithms to handle the channel time-variability. In order to improve the performance of the underwater acoustic OFDM communication system, the irregular repeat accumulate (IRA) code as a channel coding scheme is proposed in this paper. We analyzed the effect of parameters of the IRA code on the performance of the system. Computer simulation has been implemented and the sea trial has been carried out in shallow water acoustic channels near Xiamen port. The simulation results show that the IRA coding scheme has improved the SNR (signal noise ratio) performance of the system at range of 14dB to 16dB compared with the system without coding and the BER performance of the IRA code will get improvement with the increase of the code length and the iteration of decoding to a certain degree, and then tends to stable. Field test experiment results obtained with the IRA code are provided, demonstrating the feasibility of the proposed channel coding for underwater acoustic OFDM communication system.**

Keywords-chanel coding; IRA codes; OFDM; underwater acoustic communication

I. INTRODUCTION

Digital communications through underwater acoustic (UWA) channels differs substantially from those in other media, such as radio channels, due to the severe signal degradation caused by multipath propagation and high temporal and spatial variability of the channel conditions. Moreover, the available bandwidth in an UWA communication channel is severely limited by transmission loss which increases with both frequency and range. Thus combating the underwater multipath to achieve effective and reliable transmissions is without exception considered to be the most challenging task of an UWA communication system.

Multicarrier modulation (MCM) in the form of OFDM has been shown feasible for UWA communications via its ability to handle multipaths. The principle of MCM is to divide the transmission channel into a number of sub-channels or sub-carriers. Specifically, in OFDM modulation, each sub-carrier is orthogonal to the other sub-carriers. This will allow the sub-carriers spectra to overlap, thereby increasing the spectral efficiency, so that the symbol duration is much longer compared to the multipath spread of the channel. As a result, inter-symbol-interference (ISI) may be negligible in each sub-band, which avoids complex channel equalization and reduces the susceptibility to various forms of impulse noise. Experiment results have demonstrated that OFDM is a viable solution for high rate transmissions over time-varying underwater acoustic channels [1].

However, to make OFDM modulation successful in a practical underwater system, some issues must be adequately addressed.

(1) Uncoded OFDM has poor performance in fading channels, since it does not exploit the multipath diversity inherent to the channel. For example, a commonly encountered multipath spread of 10 ms in a medium-range shallow water channel, causes the ISI to extend over 100 symbols if the system is operating at a rate of 10 kilo symbols per second[2-3].

(2) OFDM transmission has large peak-to-average power ratio (PAPR), which would restrict the overall range of a wireless device, whose power is regulated by the peak, not average, power output.

Since channel coding is indispensable in practical communications systems due to the coding gain. In this paper, the irregular repeat accumulate (IRA) code that has superior performance and is linear-time encodable and decodable is adopted to solve the first problem above. And the PAPR reduction approach requires multiple rounds of encoding for each information block at the transmitter, hence, the fast encoding algorithm and iterative decoding of the proposed IRA code is well suited. In [4], a novel approach to reduce the PAPR using a modified repeat-accumulate (RA) code and signal clipping is present.

A. Current coding schemes used in underwater acoustic communications

A well-studied coding scheme from the existing literatures is often used for underwater communication systems, such as trellis coded modulation (TCM), convolutional codes and Reed Solomon (RS) codes, LDPC (low-density parity-check) codes, Turbo codes etc. Recent researches show that Turbo codes and Gallager's LDPC codes perform very close to the Shannon limit in additive white Gaussian noise (AWGN) channels and other types of channels. However, no matter what parallel or serial, Turbo codes can be encodable in linear time but

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decodable in complicated algorithm. LDPC codes using the message passing decoding algorithm (also known as the belief propagation (BP) algorithm) can be decodable in liner time, but encodable in complicated algorithm because the relationship between the code length and the complexity of the encoding algorithm is quadratic [5].

The class of irregular repeat accumulate (IRA) codes [6-7], which are encodable and decodable in linear time, was introduced by Divsalar, Jin and McEliece in 2000, who were enlightened by irregular LDPC codes. As special subclasses of both irregular LDPC codes and irregular Turbo codes, IRA codes have drawn much recent attention because they enjoy extremely simple encoding and low complexity decoding and can achieve the same performance as LDPC codes and Turbo codes. Some studies have been carried out regarding IRA codes. For example, in [8], the study of the performance of IRA codes in turbo-coded modulation and multi-level coding is present, and in [9], the performance of IRA codes in multiple input multiple output (MIMO) system is analyzed. But there are very few articles on the application of IRA codes in UWA communication system by now.

B. Structure of IRA codes

In an IRA code, a block of information bits are first encoded by an irregular repeat code. The repeated bits are then interleaved and encoded by an accumulator. The final coded bits are the collection of the information bits and the parity bits from the accumulator. Obviously, the resulting code is systematic. The process of encoding is illustrated in Fig. 1

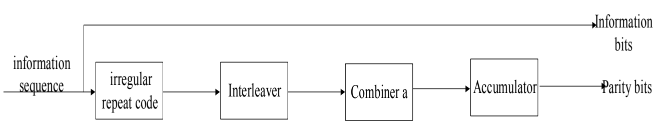

Figure 1. The encoding process of an IRA code

Similar to LDPC codes, IRA codes can be represented by a Tanner graph, shown in Fig. 2. The IRA code ensemble can also be represented by degree profiles ($f_1, f_2, \cdots f_J; a$), where f_i is defined as the proportion of the edges connected to the information bit nodes with degree i, $i = 2,3,\cdots,J$, which satisfies $\sum_{i=2}^{J} f_i = 1$, and a is the grouping factor before the accumulator, J is the maximum degree.

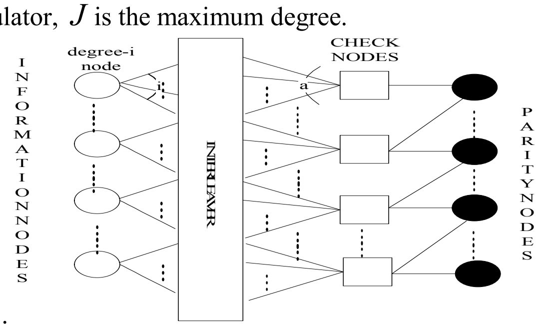

Figure 2. Tanner graph representation of an IRA code

II. SYSTEM MODEL

OFDM is a kind of multicarrier modulation technique, which converts a set of serial data stream into parallel signals, then use a set of mutually orthogonal sub-carriers to modulate the parallel signals. Extending the symbol duration cause a reduction of the deterioration of signals by multipath. As a result, inter-symbol-interference (ISI) may be neglected when a guard interval is inserted in the front of each sub-band. Fig. 3 shows the block diagram of an UWA OFDM system with IRA coding.

The IRA coded binary bits stream are mapped in QPSK modulation, which means that two by two bits are given a specified QPSK symbol. Then the data are converted from serial to parallel. This conversion is necessary because the input of the OFDM transmitter needs to be parallel in order to map the symbols onto the sub-carriers. Then the N-point inverse fast fourier transform (IFFT) is implemented to map the input signal onto a set of mutually orthogonal sub-carriers, where N is the number of sub-carriers. To solve the problem of intersymbol interference (ISI) and intrasymbol/intercarrier interference (ICI) caused by multipath, a Cyclic Prefix (CP) as a guard interval should be inserted in the front of each symbol. At the OFDM receiver, the inverse transformations (e.g. P/S (parallel to serial) & FFT) are implemented to process the received signals. After demapped and decoded, the source bits stream can be estimated.

The characteristics of underwater acoustic channel is a very important factor in the design of high-speed underwater communication system. In this paper, a 5-path channel model including time-varying fading, multipath and additive noise for the shallow water acoustic channels is built, which is adapted from Rayleigh fading channel model. Multiplicative fading of each path is implemented by introducing a time-varying and correlated fading factor to the power or the amplitude of the signal.

III. SIMULATION RESULTS

A. Simulation of performance of IRA codes in underwater acoustic OFDM system

Performances of IRA codes for OFDM system are simulated and evaluated in an underwater acoustic channel model. In the simulation, 1000 frames data are sent each time. The first sent bits stream are encoded by IRA codes with their parameters: J =50 , f_3 =0.252744 , f_{11} =0.081476 , f_{12} =0.327162 , f_{46} =0.184589 , f_{48} =0.154029 , a =8 , code rate=1/2, code length=1024 bits. In decoder, they are decoded by the BP algorithm with 5 iterations. Then the uncoded bits stream is sent to carry out the performance comparison, including the coded system and the uncoded system. Fig. 4 presents the bit-error-rate (BER) performance of the two systems. And the rate of the codes is then given by

$$R = \frac{a\sum_{i=2}^{J} f_i / i}{1 + a\sum_{i=2}^{J} f_i / i} \qquad (1)$$

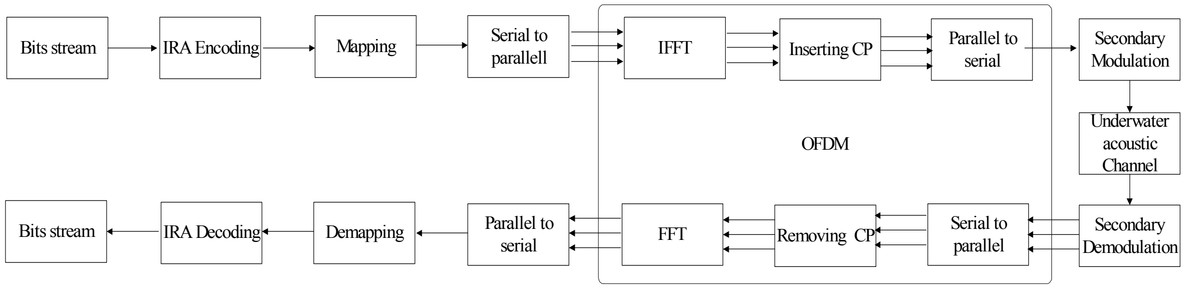

Figure 3. A schemetic diagram of IRA code underwater OFDM system

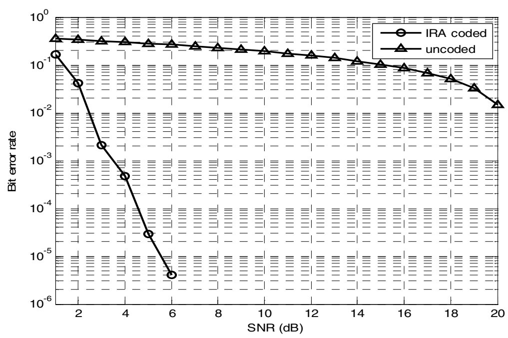

Figure 4. BERs of IRA coded OFDM system and uncoded system

In Fig. 4, the circle marked curve denotes the BER versus SNR of the IRA codes for UWA OFDM system and the curve with triangle mark represents the BER of the uncoded system. The BER of coded system lowers rapidly with the increase of the SNR of the system and can nearly be equal to zero when the SNR is above 7dB, whereas the BER of the uncoded system lowers slightly with the increase of the SNR. It can be noticed that the proposed channel coding scheme improves the SNR performance of the system by around 14dB to 16dB compared with the system without coding.

B. Study of performance of IRA codes with different parameters in underwater acoustic OFDM system

In a given communication system, selection of parameters for a kind of code can determine its performance. According to Shannon's channel coding theorem, with the increase of the code length (tends to ∞), the decoding error probability tends to zero exponentially, but the complexity of encoding and decoding algorithm would correspondingly get increased. So the study of parameters of IRA codes in communication systems is necessary to optimize its performance. This paper would focus on how the code length and the iterations of BP-decoding affects the performance of an IRA code.

To reduce of the adverse effect of propagation time delay caused by time variability of UWA channels, short-length IRA codes viz., 512 bits, 1024 bits and 2048 bits should be adopted. Fig. 5 illustrates the BER performance of the IRA code with different code length. It can be noticed that with the increase of the code length, the BER of the system lowers and the performance get improvement.

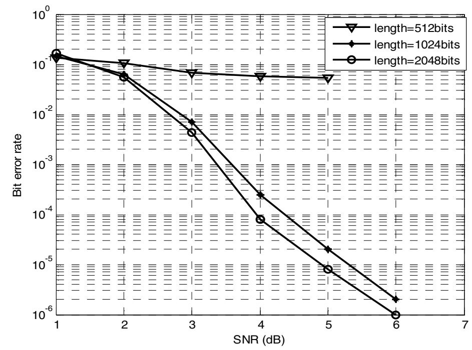

Figure 5. Comparison of BERs of IRA codes with different code length in underwater acoustic OFDM system

Fig. 6 displays the performance of IRA codes in system with different parameters, including the code length and the iterations of BP-decoding. As shown in the figure, when the code length is 1024 bits, the codes decoded in BP algorithm with 8 iterations improve the system performance by about 1dB compared with 5 iterations. The performance of 1024-bit code decoded with 5 iterations is much better than 512-bit codes with 2 iterations. When decoded with 5 iterations, the 2048-bit code only get about 0.5dB gain compared with the 1024-bit code. So it can be inferred that the performance of IRA codes decoder has gotten improved with the increase of the iterations of BP-decoding, but when the iterations increase to a certain degree, the performance of system tends to stable.

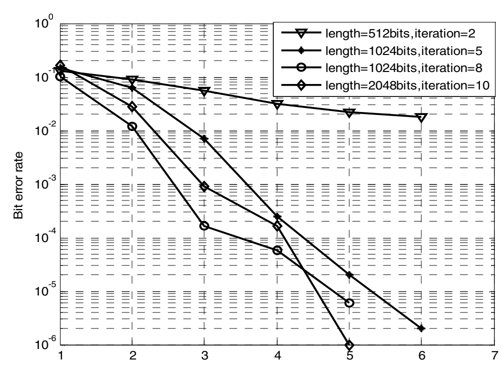

Figure 6. Comparison of BER of IRA codes with different parameters in underwater acoustic OFDM system

IV. THE RESULTS OF SEA TRIAL

The sea trial was implemented in Wuyuan bay near Xiamen port and the system specification are summarized in Tab. 1. In this experiment, the distance between the transmitting transducer and the receiving transducer is 700 m, and the data were sent for 24times.

TABLE I. SYSTEM SPECIFICATION

Parameters	Value
Method of mapping	QPSK
Bandwidth	5 kHz
Carrier frequency	15 kHz
Transmission band	12.5~17.4 kHz
Sampling frequency	60 kHz
Sub-Carrier number	1024
Symbol duration	204.8 ms
Data rate	3.906 symbols/s
Guard interval	51.2 ms
IRA code length	1024 bits

Tab. 2 displays the experimental results on the BER performance of the IRA code for underwater acoustic OFDM system. Statistics from the Tab. 2 show that the average BER before decoding is about 0.0257, while after decoding, which is about 0.002360. It can be noticed that the BER of the system has decreased by an order of magnitude, some of BERs are even equal to zero.

TABLE II. EXPERIMENTAL RESULTS

Sequence Number	BERs of sea trial		Sequence Number	BERs of sea trial	
	BERs before decoding	***BERs after decoding***		***BERs before decoding***	***BERs before decoding***
1	0.0363	0.005859	13	0.0305	0.003906
2	0.0236	0.003906	14	0.0275	0.005859
3	0.0177	0.001953	15	0.0236	0.001953
4	0.0196	0.000000	16	0.0236	0.001953
5	0.0255	0.000000	17	0.0295	0.001953
6	0.0255	0.009766	18	0.0157	0.000000
7	0.0187	0.001953	19	0.0196	0.000000
8	0.0196	0.000000	20	0.0187	0.000000
9	0.0334	0.003906	21	0.0344	0.005859
10	0.0216	0.001953	22	0.0246	0.000000
11	0.0216	0.001953	23	0.0206	0.000000
12	0.0236	0.001953	24	0.0187	0.001953

V. CONCLUTION

In this paper, the IRA code for underwater acoustic OFDM communication system is proposed. Simulation results show that the system performances can be noticeably improved by the proposed channel coding scheme. The BER performance of IRA codes will get improved with the increase of the code length and the iteration of BP-decoding to a certain degree, and then tends to stable. The permissible BER range for an underwater acoustic communication system is from 10^{-3} to 10^{-5}, so about-1000-bit IRA codes with about 5 to 8 iterations are suitable to meet the basic requirement of the UWA communication system. The sea trial results show that the BER of the system has decreased by an order of magnitude via the IRA coding scheme, some of BERs even are equal to zero, which confirm the proposed scheme can indeed improve the performance of the underwater acoustic OFDM communication system.

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